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Understanding the sound environments of babies and toddlers

A study commissioned by the

National Deaf Children's Society

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1. What is this project about?

Children live in a noisy world and this is no different for deaf babies and toddlers aged between 3 and 18 months. It is very important for young deaf children to have good access to speech, but hearing aids cannot always provide this, particularly in noisy situations and when the sound of interest is at a distance from the child. Radio aids can give better access to speech in these situations, but they do not necessarily help children hear other important sounds in the environment. Awareness of environmental sound and understanding its meaning has been shown to support child cognitive development and learning. This research project was developed to understand the sound environments of both deaf and hearing babies and toddlers, and to compare their experiences. We then used this information to make recommendations about what to do next to help deaf young children get access as much meaningful sound as possible.

2. How did we carry out the project?

- We asked forty families with either a deaf or a hearing baby to tell us about the sound environments of their everyday lives.
- We compared what they told us to find out whether deaf babies were missing out on sounds and experiences that are supportive for their development.

Understanding the sound environments of babies and toddlers

3. What were the findings?

- The sound environment for both deaf and hearing babies is complex.
- Parents of deaf babies do change the environment to some extent particularly at home, to make things quieter, and to be closer to their child.
- Hearing babies have greater awareness of environmental sounds compared to deaf babies.
- Deaf babies are in noisy situations for a third of the time.

4. Recommendations

- Professionals should consider the full sound environment of deaf children under 18 months of age when recommending technologies to parents.
- With good guidance for use, radio aids would be beneficial for deaf children under 18 months of age, enabling parents to use radio aids effectively.
- Further research should identify the finer requirements for the use of radio aids for access to both speech and the meaningful sound environment for deaf children under 18 months of age.

1 Executive summary

Children live in a noisy world and this is no different for babies and toddlers aged between 3 and 18 months. In the first months of life, children are exposed to a variety of sounds in the environment which help shape their 'world picture'. The sound environment is rich and multifaceted, providing ample opportunities for learning about the world, but deaf babies and young children may miss out on important sounds around them. For deaf children acquiring spoken language, it is crucial that they have good access to the sounds of speech as early as possible. Typically hearing babies, in addition to having access to speech more routinely, also learn to understand other meaningful sound in their environments which support their development, and well before one year of age they are also able to make sound-object associations. Hearing aids and cochlear implants are able to provide some access to sound, but they perform less well in noisy environments and when the sound of interest is at a distance. It is well evidenced that remote microphone technologies such as radio aids allow for a clearer speech signal in challenging listening situations, but less is known about whether and how the use of this technology may impact learning opportunities – both positively or negatively – from other meaningful sound in a child's daily living and learning environment.

This study recruited forty families in order to explore the sound environments of deaf and hearing babies and toddlers aged between 3 and 18 months and to compare their experiences. Comparisons were made between the two populations to describe their respective sound environments and to determine whether parents of deaf children made changes to the sound environment or how they interacted with their babies in those environments compared to parents of hearing children. This

information was used to inform initial recommendations about technology use for the management of deaf children.

Highlighted findings

- The sound environment for both deaf and hearing babies is complex.
- Parents of deaf babies adapt the sound environment particularly at home, to make things quieter, and to remain closer to their child. This may limit the child’s opportunity to explore and learn from their environment.
- Hearing babies have greater awareness of environmental sounds compared to deaf babies.
- Deaf babies are in noisy situations for a third of the time.

Recommendations

- Professionals should take into account the full sound environment of deaf children under 18 months of age when considering and recommending technologies to parents.
- Radio aids will be beneficial for deaf children under 18 months of age provided that there is clear guidance for their use in differing contexts and situations, and which is tailored to the individual families’ needs.
- Further research should identify the finer requirements for the use of radio aids to ensure access to both speech and the meaningful sound environment for deaf children under 18 months of age.

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1 Background

The Quality Standards for use of personal radio aids; promoting easier listening for deaf children published by the National Deaf Children's Society and the UK Children's FM Working Group states that "In an ideal world, every deaf child would receive a complete amplification package, including a radio aid, at first fitting" (National Deaf Children's Society, 2017, page 5). Whilst there is ample and powerful evidence for the benefits of using radio aids in school aged children, and less but still strong evidence for use with preschool children, there is little or no published research in relation to children in the first year to 18 months of life. Because of the well-known benefits of enhancing access to the speech signal for children developing spoken language, many audiology and education professionals feel instinctively that use of a radio aid must confer advantages, even in the earliest months. However, a typically hearing child also has the opportunity to 'overhear' in their everyday communication environment and to access a range of environmental sounds which may enhance their cognitive and sensory-motor development and understanding of the world around them. It is therefore important to understand whether and how use of a radio aid with babies and toddlers may impact on these opportunities, and to consider any potential drawbacks as well as benefits.

1.1 Auditory development and the development of auditory attention

In a typically developing child, auditory development is a prolonged process, and progresses through three stages: 1) maturation of sound coding; 2) maturation of selective listening and discovering new details in sound; and 3) maturation of perceptual flexibility (Werner, 2007). In the first stage of auditory development (full term birth to 6 months) the auditory system's ability to encode sound matures, but it is not until the second stage, which lasts until a child is about 5 years old, that the ability to focus on specific features of sound matures. Most typically hearing children master selective listening by the time they start school. The third stage, which sees increased sophistication in listening abilities in different listening conditions lasts into adolescence. The immaturities in infants' hearing affects their ability to learn from sound in real environments, and it is important to consider the sound (and noise) environments which infants experience in their daily lives with the aim of optimizing auditory learning opportunities. This assumes even higher importance for a deaf child developing communication through audition, and Erber (1977) emphasised a hierarchy moving from awareness through to discrimination, identification and onto comprehension in relation to the development of speech in deaf children.

In terms of auditory attention, four components have been recognised: arousal; orienting (i.e. noticing and responding to a source e.g. with eye movement); selective attention; and sustained attention (Gomes et al., 2000). Infants at 3 months of age have been shown to prefer speech to other naturally occurring sound signals (Shultz & Vouloumanos, 2010), and this persists in infancy, with Krentz & Corina, (2008) also noting that infants under 10 months show a preference for listening to verbal rather than nonverbal sounds. However, it has also been shown that babies begin to identify the relationship between sound and objects at around 7 months (Cummings et al., 2009), and that in investigating infant recognition of meaningful verbal and non-verbal sounds with children of 15, 20 and 25 months old, it was noted that sound-object associations increased with age. The study also suggested that children who are more sensitive to these observations may also be more attentive generally to distinguishing characteristics in their environments and may have larger vocabularies.

Some studies have sought to understand the role of ‘overhearing’ on children’s language development. Akhtar et al. (2001) demonstrated that children of 18 months and 2 years of age can learn object labels by overhearing and in a later study found that learning object labels through overhearing was possible even when distracted (Akhtar, 2005).

1.2 Cognitive development

Piaget proposed four stages of cognitive development, in which the first, covering birth to 2 years of age, is categorised as the ‘sensori-motor’ stage. During this stage children learn about their environment through their senses and motor activities. The US Centers for Disease Control and Prevention (the US’s leading science-based national Public Health agency) describes the first year of life as one in which “babies learn to focus their vision, reach out, explore, and learn about the things that are around them” with their cognitive development encompassing the growing skills of memory, language, thinking and reasoning (Centers for Disease Control and Prevention, n.d.).

A number of researchers have evidenced the significance of the relationship between motor development and language development in infancy (Campos et al., 2000; Iverson, 2010; Libertus & Violi, 2016), identifying that the emergence of motor skills in infants – both fine motor skills such as manipulation of items in the hands and gross motor skills such as crawling and walking – enables them to interact with objects and people in ways in which promote language development as well as cognitive learning. Sound awareness can clearly be a motivator for the infant to interact physically with objects in both the immediate and surrounding environments.

1.3 The sound environment as motivator for development

Building on what is known from academic research and expert observation in the field of childhood development over many years, organisations which provide information and support for parenting (including those which focus specifically on the promotion of language and communication development in typically hearing children, as well as those with deafness) offer an abundance of advice and guidance – substantially online – on optimally supporting infant and toddler development in the home. Such advice routinely includes stimulating development and motivating auditory learning by attending to environmental sound as a way to naturally introduce new language and encourage exploration. In the context of early cochlear implantation for example, detailed support and guidance materials are available for parents via the implant manufacturer companies, designed to support the professional rehabilitation strategies and support given by implant centres. Strategies emphasised include activities to help young children recognise and attend to environmental sounds, therefore understanding their importance (for example, doorbell, microwave, toilet flushing or sound of food preparation). Routinely recognising the sound of the doorbell promotes understanding that it may herald a visitor's arrival; other sounds may indicate food is coming, even when its preparation cannot be seen. Learning about environmental sounds in this way, both indoors and out, enables infants and young children to understand the context of the sounds they hear and to learn to anticipate and react appropriately, giving a greater sense of awareness of the world around them.

1.4 The limitations of hearing aids and cochlear implants

Hearing speech in noise, at a distance, and in reverberant spaces are all major challenges for those who are deaf/hard of hearing. Hearing aids and cochlear implants work best at 1-2 metres in quiet non-reverberant rooms but this is not the reality of the world in which children live (Benítez-Barrera et al., 2020). The evidence for the use of digital features such as noise reduction and directional microphones in children under 18 months is limited, and guidelines tend to suggest that some of these features be deactivated for young children (American Academy of Audiology, 2013). Directional microphones may impair localisation abilities as well as reducing sound awareness and interfering with the ability to overhear in young children (American Academy of Audiology, 2013). Although noise reduction is generally considered not to impair speech recognition in children (Crukley & Scollie, 2014; Pittman, 2014), studies in those under 18 months are lacking.

The benefits of using remote microphone technology such as radio aids with preschool children (aged approximately 2-4 years old) are becoming increasingly widely appreciated, as research evidences positive gains in relation to speech perception and speech and language development with this age group (Allen, Mulla, Yen Ng, et al., 2017; Benítez-Barrera et al., 2018; Mulla & McCracken, 2014). Studies have also demonstrated acceptability to parents, who have welcomed the technology particularly to overcome the challenges of distance and noise, thereby enabling enhanced access to speech in a variety of social and early learning settings

(Allen, Mulla, Ng, et al., 2017; Statham & Cooper, 2013). There has however been little focus on the use of this technology with infants and young children under 18 months of age.

Audibility of the speech signal has understandably been prioritised as this is of fundamental importance to spoken language development, the success of which has consequences for many factors including social development, educational attainment and emotional wellbeing (Ching et al., 2018, 2021; Culbertson & Gilbert, 1986). Parents of hearing children may maintain communication and contact, and offer reassurance to their child when further away than an optimum hearing aid distance of one to two metres. Children under the age of four years may spend around a quarter of the day in noisy environments (Jones & Launer, 2010). It is necessary though to consider what we mean by the term 'noise'. In audiology, 'noise' generally refers to sound that interferes with the speech signal. However, all sounds in the real-world environment are produced by actual events that have meaning by virtue of the causal events (Ballas & Howard, 1987). This means that all sounds in the environment (including, but not limited to speech) may be pertinent to a child's development and learning.

The field of remote microphone technology is advancing rapidly and therefore the need for evidence and guidelines is becoming ever greater. Although there have been some small practical trials with younger children in services where Audiologists and Educational Audiologists/Teachers of the Deaf feel positive about, and can resource, the equipment to implement the provision, the feeling persists amongst some professionals that radio aids principally serve to enable access to education settings. A recent study by the UK National Deaf Children's Society in conjunction with the Ear Foundation, Nottingham, however, has reinforced the perception of benefit by most, but not all, participating parents of preschool children (mostly aged 3 to 5 but a few as young as 18 to 24 months) in wider situations, and clearly further evidences the positive impact on adult-child communication and interaction in the family context (Allen, Mulla, Ng, et al., 2017).

1.5 Aims of study

The aims of this study were to:

1. Describe and analyse the sound environments to which deaf hearing infants and young children between 3 and 18 months are typically exposed, mapping their everyday routine experiences and interactions with their families to assess auditory access and environmental awareness or unawareness.
2. Compare deaf and hearing infants' experiences to discover whether parents of deaf children make changes to the environment compared to parents of hearing children.
3. Identify issues to support the development of guidelines for using radio aids for this age group to not only ensure essential high-quality access to speech, but also to understand the importance of other sounds in the environment.

2 Participants and methods

2.1 Ethical considerations

The study was approved by the UCL Research Ethics Committee (project ID: 12585/005). Informed consent was given by all participants. Data were stored in compliance with the European Union's General Data Protection Regulation (2016/679). Personal identifiers were removed for analysis.

2.2 Recruitment

Parents of deaf and hearing children age between three and 18 months were eligible to take part in the study. Those who were unable to access online tools in written English were excluded. Information about the study was sent to Qualified Teachers of the Deaf (QToDs) via professional mailing lists. QToDs then gave study information to families who met the entry criteria. The National Deaf Children's Society included the study on their mailouts to families. Interested families then filled in an online contact and expression of interest form that included a basic eligibility check (age of child). The study team subsequently contacted the interested families either by telephone or by email with further details about the project which included a link to a video and explanation on a website. A link to a consent and demographics questionnaire was included in the email. Once the participant had consented to the study, they were sent a link to their individual survey.

In order to recruit parents of hearing babies, participants with deaf babies were asked to forward study information to friends or acquaintances with hearing babies in the study age range. This helped to ensure that the sample of parents with hearing babies was reasonably similar in terms of socioeconomic status and geographical areas to the parents of deaf babies. A public and patient involvement (PPI) survey was carried out prior to the start of the study to ensure that this was an acceptable method of recruitment for parents of young children.

2.3 Procedures

All data collection took place online using the web-based survey tool, Opinio, between May 2021 and January 2022. For part of this time, some COVID-19 pandemic restrictions were still in place in the UK. Demographics information collected included data about parental education level, child's hearing status and any amplification (deaf babies only), parental awareness of radio aid technology (deaf babies only), family history of hearing loss, and whether the child had any additional needs.

An online survey was devised specifically for this study and was customised to capture the 'soundscape' (sounds in the environment) to which both deaf and hearing infants and young children between 3 and 18 months were typically exposed to in their everyday lives. The survey attempted to map everyday routine experiences and interactions with their families to assess auditory access and environmental awareness or unawareness. The survey was piloted by two families and revisions to instructions were made based on their feedback. The survey asked parents to report the following for each observation:

- Activity taking place.
- Sounds in the environment.
- Estimates of distance from child.
- Whether child noticed sounds in the environment.

Participants could add up to five environmental sounds per recording. They were asked to record their observations several times per day across three days and were given a £20 voucher if they completed at least 12 observations.

2.4 Participants

Sixty-five people filled in the screening questionnaire. Five were ineligible as their child was over 18 months old. Twenty people did not respond following email invitation and two reminders. Forty families (represented by 39 mothers, one father; 22 with deaf children and 18 with hearing children) consented to take part in the study. Two subsequently withdrew from the study (both from the deaf group). A further eight participants were unable to complete observations (six from the deaf group, two from the hearing group) and their data were removed from the final analysis. The final group comprised 30 participants: parents of 14 deaf babies and 16 hearing babies. Group characteristics and between group comparisons are shown in Table 1.

There were no observed differences between groups on any of the participant characteristics or the number of observations completed. Parental report of family history of deafness was similar between groups. However, on closer inspection, the three parents in the deaf group reported immediate family history (sibling or parent with permanent hearing loss), whereas the two parents reporting family history in the hearing group described deafness in grandparents or uncles/aunts.

All parents in the deaf group reported that their child had been diagnosed with hearing loss within 8 weeks of birth. All had bilateral hearing loss and parent descriptions of severity ranged from mild-moderate to profound loss (one parent did not know the severity of their child’s hearing loss). Twelve children wore bilateral hearing aids while two were unaided. None of the children had received cochlear implantation. One child had a radio aid, and twelve parents reported knowledge of radio aids. The two parents who reported no knowledge of radio aids were those whose children were unaided.

2.5 Data analysis

Conceptual content analysis was used to categorise the parent reported sound environments (Graneheim & Lundman, 2004). Parents' descriptions of the sound environments were read and coded independently by two members of the research team (HEC and GC). No sounds were excluded (e.g. both background and child directed speech were included for coding). Meaning units were agreed upon following discussion and parent descriptions were again coded according to these meaning units. Discrepancies were resolved through discussion and debate. A third coder (AD) reviewed and checked all coding. T-tests, ANCOVA and Chi square testing was used to evaluate the differences between groups on quantitative and coded qualitative data where appropriate.

3 Results

3.1 Sound environments of deaf and hearing babies

Conceptual content analysis showed that children were in a variety of different sound environments during the day. Eight codes were extracted which related to the main sound environment. Reported situations were assessed and an overall description of each sound environment was developed. This included inside and outside environments, home and public environments, and loud and quiet situations. A single main sound environment category was then allocated for each entry recorded by participants. Eight further codes were identified relating more specifically to the sounds present in the environment. Again, all reported situations were evaluated and categories were developed including household sounds, background media, speech and transport. Up to two specific sound categories with allocated to each observation. Categories, examples and counts are shown in Table 2.

Comparisons between the sound environments of deaf and hearing babies were made in order to determine whether parents of deaf babies changed the environment relative to hearing babies. Figure 1 shows group differences in sound environments. Chi square testing showed no significant difference overall between groups for main sound environment (χ^2 =13.87, *p*=.054; see Figure 1A). However, post-hoc testing revealed that deaf children were in inside noisy home environments significantly less than hearing children (*p*<.050, Bonferroni corrected). Chi square testing showed that there was a significant difference overall between groups for subsidiary sound environments and background sounds (χ^2 =20.58, *p*<.005; see Figure 1B). However, post-hoc pairwise comparisons (Bonferroni corrected) were unable to identify where the differences lay.

Grouping all noisy and all quiet situations together showed that deaf babies were in noisy situations 33% of the time and hearing babies 42% of the time. There was no significant difference between groups (χ^2 =2.24, *p*=.134) for total time in noisy situations.

Table 1 Participant characteristics and between group comparisons

Variable	Deaf group (n=14) M (SD)	Hearing group (n=16) M (SD)	Statistic	*p*	Effect size	95% CI
Age of child (months)	9.74 (4.14)	9.68 (4.95)	t=0.03	.973	0.01	[-0.74, 0.76]
Parental education level (SS:C/V:UG:PG:NS)	0:3:7:3:1	0:1:7:8:0	χ^2 = 4.16	.245	9.70	-
Family history of deafness (yes:no)	3:11	2:14	χ^2 = 0.03	.870	1.17	-
Additional needs in child (yes:no:not stated)	1:13:0	0:15:1	χ^2 = 0.00	.972	1.03	-
Number of observations completed	11.57 (6.61)	11.38 (4.96)	t=0.09	.928	0.03	[-0.72, 0.78]

All comparisons on scale data were *t* tests. Group comparisons on family history and additional needs were done using chi-square tests. Effect size = Cohen's d for *t* tests, and odds ratio (OR) for chi-square tests. CI = confidence interval. Parental education level abbreviations: SS = secondary school; C/V = college/vocational; UG = undergraduate; PG = postgraduate; NS = not stated.

Table 2 Sound environment codes and examples

Category	Sub-category	Example	Meaning unit count
Main sound environment	Inside quiet public environment	Library/quiet shop	0
	Inside noisy public environment	Coffee shop/noisy shop	18
	Outside quiet public environment	Trees rustling	11
	Outside noisy public environment	Walking next to traffic	25
	Inside quiet home environment	Playing quietly	203
	Inside noisy home environment	Sibling shouting/bath time	75
	Outside quiet home environment	One child playing in the garden	9
	Outside noisy home environment	Multiple children playing in the garden	4
Subsidiary sound environments and background	Quiet household sounds	Bags rustling	2
	Loud household sounds	Washing machine/hoover	5
	Loud external sounds	Building work outside home	2
	Background media	Background TV/radio/music etc	111
	Child directed speech – adult	Parent talking to child	73
	Child directed speech – child	Sibling talking to child	23
	Background speech	Multiple background talkers in coffee shop	87
	Transport	In the car/on the bus	11

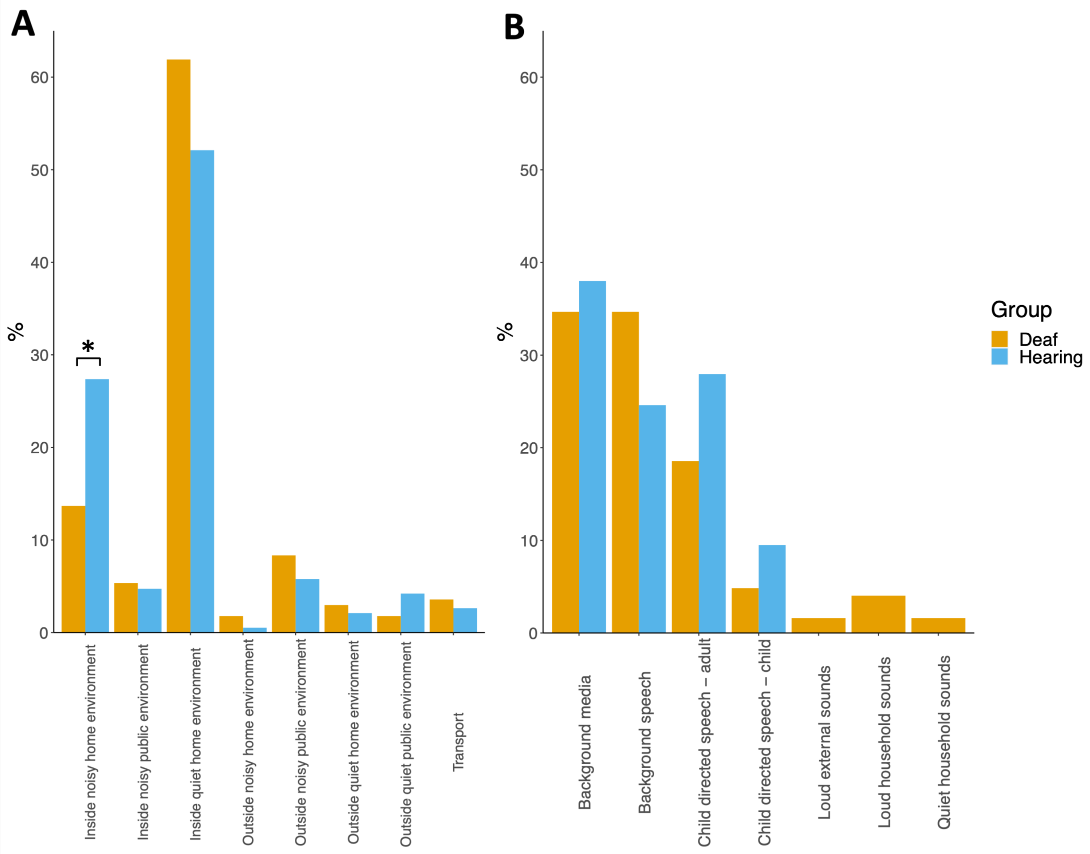

Figure 1 *Panel A shows the main sound environments children were in. Panel B shows subsidiary sound environments and backgrounds.*

3.2 Awareness of environmental sounds

Parents reported that hearing babies noticed significantly more environmental sounds than deaf babies (χ^2 =52.18, *p*<.001; see Figure 2). Parents of deaf babies also reported that they were unsure whether their child heard a sound more often than parents of hearing babies (post hoc testing *p*<.01).

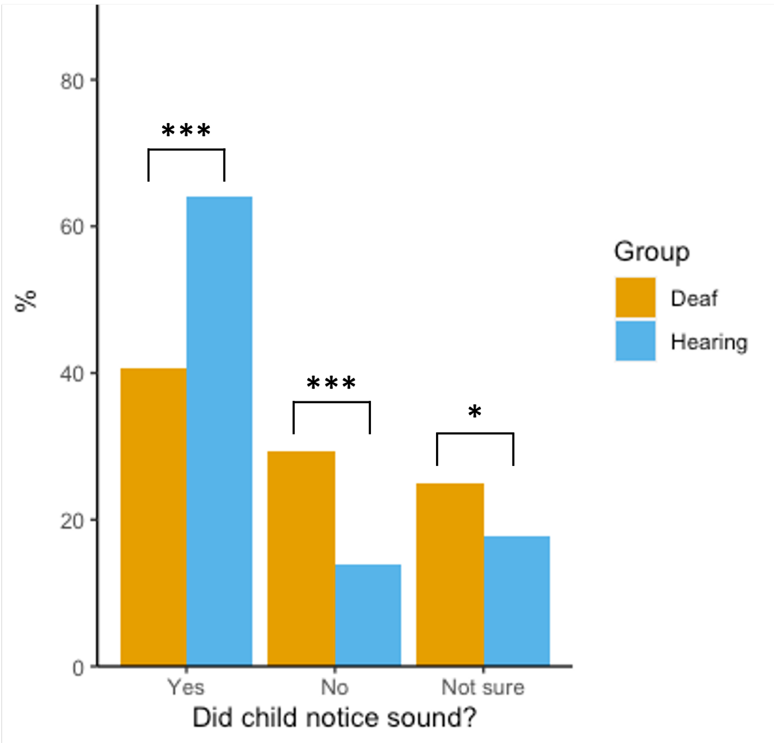

Figure 2 *Parent report of whether child noticed environmental sounds.*

3.3 Distance from child to parent

The amount of time children were close to their parent (defined as being held or up to arm's length away) was not significantly different between groups with deaf babies being close 65% of the time and hearing babies being close 60% of the time (χ^2 =3.47, p=.063). However, when parents reported that they were at a distance from their child (defined as being greater than arm's length away) they estimated that deaf babies were significantly closer than hearing babies when controlling for age ($F(1,457)=12.24$, $p<.001$) with deaf babies being at a mean distance of 1.5 m and hearing babies at a mean distance of 2 m (see Figure 3).

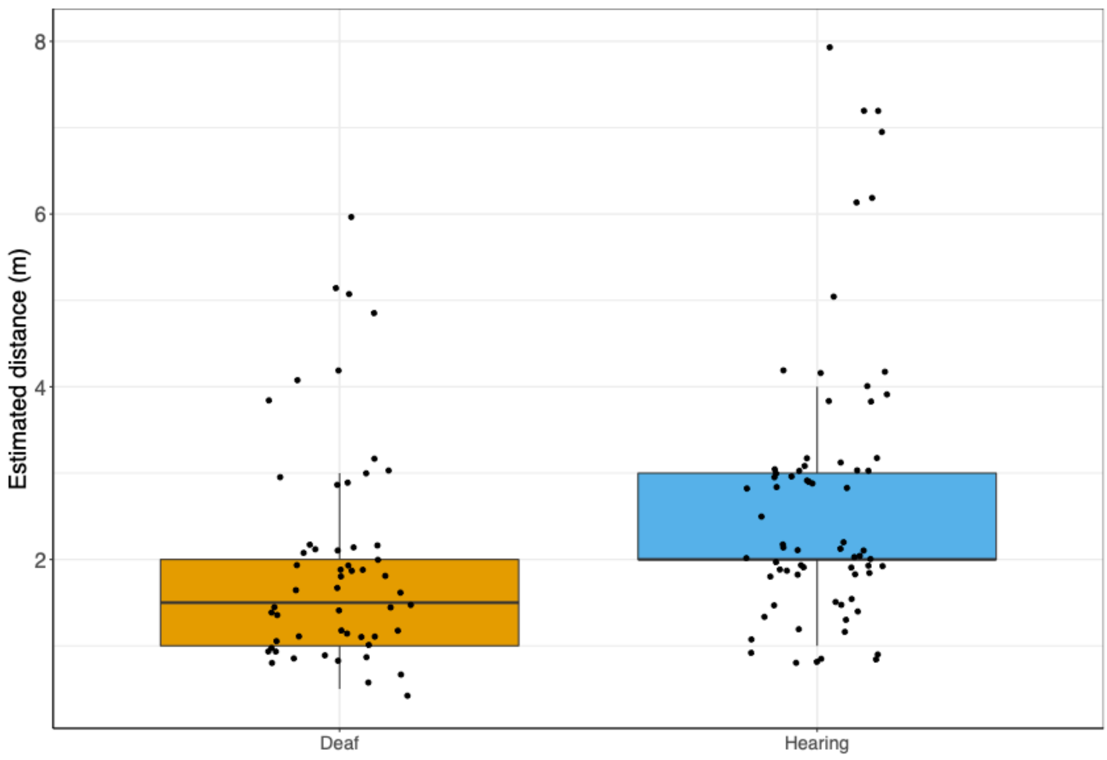

Figure 3 *Parent estimated distance (in metres) from parent to child when at greater than arm's length away.*

3.4 Example situations

Data collected by many participants were rich in information and illustrated complex scenes and family interactions. Here, we give two examples to demonstrate the multifaceted sound environments in which deaf babies and toddlers were commonly immersed.

Example 1 – inside noisy home environment

This situation was recorded by the parent of a deaf baby aged 9 months: The baby was sitting in a highchair with one parent sat facing the baby and feeding them. The parent felt their baby heard them speaking within this close environment. The other parent was in the same kitchen area washing up and preparing food. There was cutlery on the table at arm's length that the parent felt the baby heard when it was moved. The kettle was reported to be boiling at a distance of roughly 1 m which again, the parent felt the baby could hear. Pans were also boiling on the hob but the parent was unsure whether their baby could hear that. The tap was also running in the kitchen and the parent felt the baby could hear that.

The sound environment therefore provided many opportunities for the child to note the sound or for the parent to direct shared attention to the sound and its meaning. Use of a radio aid could have facilitated access to both the environmental sounds and any contingent conversation between the two parents.

Example 2 – outside noisy public environment

This situation was recorded by the parent of a deaf baby age 4.5 months: Parent was out walking with baby in the pram. The baby's grandmother was also present, and mum and grandma were talking to each other at an approximate distance of 1.5 m from baby – the parent was not able to assess whether the child heard them or not. There were cars on the road at a distance of about 4 m – again the parent was not sure whether their baby heard the cars. Trees were rustling and birds singing at a distance of about 3 m and the parent felt that their baby did not hear those sounds.

Again, a radio aid would have provided the opportunity for the mother and grandmother to talk to the baby in what was a noisy environment, and potentially to highlight the sounds of the birds and trees, which otherwise would not be noticed.

4 Discussion

The primary aims of this study were to map the everyday sound environments of deaf and hearing babies and toddlers, and to compare their experiences. This study has shown that parents of deaf babies make changes to their child's environment including reducing noise at home and keeping their child closer compared to hearing babies. Promotion of good hearing tactics and communication environments is a key part of the role of professionals working with families of deaf children, as is relating an understanding of the limitations of hearing aids. It is clear from our findings that parents have an understanding of this advice and put it into practice to support positive listening environments for their children. However, we need to consider whether changing the environment of deaf babies and toddlers because of the limitations of hearing aid and cochlear implant technologies may be detrimental to their development. If they are unable to stray further from their parent than 1-2 metres, this may limit their opportunities for learning and development as they become mobile. There may be crucial benefits for radio aid usage in this situation, enabling an increasingly mobile deaf child to maintain clarity of speech access whilst still being at a distance from the parent, in common with typically hearing children.

Our findings that deaf babies are in noisy situations for 33% of the time is similar to Jones & Launer (2010) who showed that deaf children under the age of four years may be in noisy environments for a quarter of their day. Without the use of a radio aid, a clear speech signal may be hard to achieve for a substantial period of a deaf child's day. However, we do need to think about meaningful sounds which may be found within 'noise', and radio aid usage, at this age in particular, will need to be managed carefully in order to ensure meaningful environmental sounds are not excluded, and can be capitalised upon to promote both conceptual understanding and vocabulary learning. The signal to noise ratio (SNR; the speech signal alone minus the background noise) of deaf children's typical home environments was investigated by Benítez-Barrera et al. (2020). They showed that the average SNR for children aged between 2 and 5 years was approximately +7.9 dB and while this may indicate a relatively quiet environment, it is below the +15 dB recommended by the American Speech-Language Hearing Association (2005).

Unsurprisingly, this study has shown that hearing babies have a greater awareness of environmental sounds compared to deaf babies. This is likely to mean that deaf children have fewer opportunities to explore their sound environments as parents will often use a cue from their child to talk about what is happening around them, thereby reinforcing learning and curiosity (Curtin et al., 2021). The ability of parents to follow their deaf child's lead in interactions and communication has been shown to be correlated with deaf children's word production (Vohr et al., 2010), and parental sensitivity (i.e. the responsiveness of the parent to their child's attempts at communication) is a predictor of language function (Pressman et al., 1999).

A striking finding of this study is that deaf children are in environments with background media (mostly television) 35% of the time and hearing children 38% of the time. Television was only occasionally reported to be the primary activity and was mostly reported as an environmental sound in addition to the main activity. While screen viewing is not necessarily of detriment to babies and toddlers per se, poor quality television, such as background television, is related to lower vocabulary

(Guellai et al., 2022). This is particularly pertinent for deaf babies as delays in language development continue to exist despite early identification and intervention (Werfel et al., 2022). However, shared attention to the television providing a stimulus for conversation could be a beneficial activity and support vocabulary growth. Sensitive use of a radio aid could enhance access to this activity.

The complexities of mapping the sound environment accurately mean that evaluating the impact of 'missing out' on sounds in the environment is challenging to measure. A plethora of previous studies have used the LENA system for analysing the language environment of babies and toddlers (see Wang et al. (2017) for a review). LENA is a system where a child wears and receiver on their body and the parent wears a microphone for around 10 hours per day, and the sound environment is recorded. LENA is able to segment audio files into live human sounds and background sounds, including child speech, adult speech and background sounds such as TV/electronic noises. This may initially appear to be helpful for the current question, however it is not able to assign importance to background sounds. This is problematic as environmental sounds can effectively be considered as a form of language as they are produced by real events and therefore have meaning associated with them (Ballas & Howard, 1987). This study sought to capture parents' experiences and observations with their babies with an emphasis on considering all sounds in the environment, rather than focusing on speech.

There are two important factors to consider here: firstly, the limitations of technology, and secondly, the priority of the speech signal. We may question whether prioritising the speech signal over other environmental sounds (as when we use a radio aid) is the best approach. However, we must be aware that current hearing technology is limited when sounds of interest (which may not necessarily be the speech signal) are at a distance or there is competing noise. The complexities of using a radio aid to give young children access to other sounds of interest (such as the doorbell ringing, birds singing, household appliances) are such that the use of this technology is limited to speech. Our research has shown though, that one microphone is unlikely to capture all child direct speech, and two microphones are likely to be preferable to enable greater access to speech sounds. Both examples above shows that one microphone would give access to only one half of a conversation, with competing sounds meaning that hearing aids alone may have limited benefit in these situations. This is supported by evidence from Benítez-Barrera et al. (2020) who suggest that radio aids should be used consistently in the home (albeit with slightly older children to those investigated in our study), but with caution so that access is not limited to a single speaker.

Hearing aid and cochlear implant technology is likely to go through a revolution in efficacy over the next few years as artificial intelligence and deep learning technologies are applied to processing strategies (Lesica et al., 2021). However, these advances are some way off being readily available and it is important to consider now how best to use remote microphone technologies as well as other assistive listening devices to optimally support deaf babies and toddlers. Radio aids are often seen as educational, or more commonly, ‘school’, devices. With learning and development happening most rapidly in the youngest age groups, it is fundamental that we optimise the use of technologies for deaf babies and toddlers, and this includes appropriate use of remote microphones. Radio aids are powerful tools for overcoming some of the limitations of hearing aids and cochlear implants but innovative use of devices is not common. It may be possible to use remote microphones along with other assistive devices (e.g. flashing doorbells) to promote spontaneous recognition of sounds in the environment (not limited to speech), and further research is needed to establish guidance for this.

This work has shown that radio aids may be a key tool for deaf children age 3 to 18 months who use hearing aids and/or cochlear implants, as they are often in noisy sound environments which may make speech intelligibility difficult. However, it is important to recognise the salience of environmental sounds and therefore, in common with Benítez-Barrera et al. (2020), we suggest that radio aid guidance should be individualised for each family and not just issued without specific guidance.

4.1 Limitations

There are several limitations which should be considered when evaluating this study. Firstly, the sample size was small and not all those who consented to the study were able to record any observations. This was potentially a challenging study for parents of very young children with many competing priorities, and also during a time when COVID-19 restrictions still impacted on their daily lives. Secondly, the survey was relatively cumbersome and relied on parents remembering to fill it in during the day. An app which had more straightforward navigation and was able to send push notifications would have been preferable but the budget was not available to develop this. Thirdly, there is an inherent difficulty in categorising environmental sounds. As Ballas & Howard (1987) observed, sampling all sounds which may occur in the environment would be virtually impossible, and therefore there is an inevitable amount of subjectivity and conjecture when coding such sounds. However, we used two independent coders and a third independent checker in order to mitigate this issue as far as possible.

4.2 Further work

Two related projects are currently in progress which will capitalise on the work of this project. The first aims to collect and explore the insights and experiences of professionals who work with deaf babies and children (namely Qualified Teachers of the Deaf, paediatric audiologists, and any other professionals who work in the field) about the use of radio aids for deaf children under 18 months of age. A survey has been developed to examine the issues present and is currently open for participation. The aim of the second project is to explore the opinions of parents of deaf children including finding out about their knowledge of radio aid systems, the benefits and challenges for use, technology and policy. This qualitative project (currently in set-up) will ensure the views of parents and families are captured, giving them a voice in this important debate.

5 Conclusion

This study has shown that the sound environments of both deaf and hearing babies are rich and complex, with many opportunities for experiencing and learning about the world. Parents of deaf young children change the sound environment, particularly in the home, to ensure that it is quieter and their child is closer, in order to achieve better listening conditions for speech. However, deaf young children are in noisy environments for a third of their day meaning that they are often in situations where hearing aids or cochlear implants will not give them good access to sounds, particularly speech sounds. Radio aids may be of benefit in these situations, overcoming issues of noise and distance from the speaker, and considerations need to be given to the optimal use of this technology in order to facilitate awareness of important environmental sounds as well as crucial access to speech. This is important as there is evidence that the sound environment can enrich development, and therefore further research is needed to ensure that hearing technologies, including radio aids, can be used to maximise access to the full soundscape for babies and toddlers.

6 Recommendations

- **Professionals should take into account the full sound environment of deaf children under 18 months of age when considering and recommending technologies to parents.** This includes thinking about noises in the environment which deaf children may not have access to, even with their hearing aids/cochlear implants.
- **Radio aids will be beneficial for deaf children under 18 months of age provided that there is clear guidance for their use in differing contexts and situations, and which is tailored to individual families' needs.** This study has shown that deaf children of this age are in noisy situations for about a third of their day and, given the known limitations of hearing aids and cochlear implants, they will not be receiving adequate access to the speech signal during this time without a radio aid. However, their parents change the environment to enable easier listening for their deaf young children, particularly at home. Therefore, a radio aid will be needed in some environments but not others. Professionals should work together with parents to analyse and understand their child's environment and identify when a radio aid will be useful.
- **Further research should identify the finer requirements for the use of radio aids for access to both speech and the meaningful sound**

environment for deaf children under 18 months of age. Innovative use of radio aid technology, potentially in conjunction with other assistive devices, needs to be explored for this age group in order for young deaf children to have access to a rich sound environment which we know to be an important motivator for development.

7 References

Akhtar, N. (2005). The robustness of learning through overhearing. *Developmental Science*, *8*(2), 199–209. https://doi.org/10.1111/j.1467-7687.2005.00406.x

Akhtar, N., Jipson, J., & Callanan, M. A. (2001). Learning words through overhearing. *Child Development*, *72*(2), 416–430. https://doi.org/10.1111/1467-8624.00287

Allen, S., Mulla, I., Ng, Z. Y., & Archbold, S. (2017). *Using radio aids with pre-school deaf children (white paper)*. *June*. https://doi.org/10.13140/RG.2.2.10415.02724

Allen, S., Mulla, I., Yen Ng, Z., Archbold, S., & Gregory, M. (2017). *Using radio aids with pre-school deaf children*.

American Academy of Audiology. (2013). *Clinical Practice Guidelines Pediatric Amplification*. *June*, 60. http://audiology.org/resources/documentlibrary/Documents/PediatricAmplificationGuidelines.pdf

American Speech-Language Hearing Association. (2005). *Guidelines for Addressing Acoustics in educational settings*. *15*(2), 1–9. http://www.asha.org/uploadedFiles/elearning/jss/6173/6173Article4.pdf

Ballas, J. A., & Howard, J. H. (1987). Interpreting the language of environmental sounds. *Environment and Behavior*, *19*(1), 91–114. https://doi.org/10.1177/0013916587191005

Benítez-Barrera, C. R., Angley, G. P., & Tharpe, A. M. (2018). Remote Microphone System Use at Home: Impact on Caregiver Talk. *Journal of Speech, Language, and Hearing Research*, *61*(2), 399–409. https://doi.org/10.1044/2017_JSLHR-H-17-0168

Benítez-Barrera, C. R., Grantham, D. W., & Hornsby, B. W. Y. (2020). The challenge of listening at home: Speech and noise levels in homes of young children with hearing loss. *Ear and Hearing*, 1575–1585. https://doi.org/10.1097/AUD.0000000000000896

Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E. M., Hertenstein, M. J., & Witherington, D. (2000). Travel Broadens the Mind. *Infancy*, *1*(2), 149–219. https://doi.org/10.1207/S15327078IN0102_1

Centers for Disease Control and Prevention. (n.d.). *Child Development: Infants (0-1 years)*. Retrieved February 4, 2023, from https://www.cdc.gov/ncbddd/childdevelopment/positiveparenting/infants.html

Ching, T. Y. C., Cupples, L., Leigh, G., Hou, S., & Wong, A. (2021). Predicting quality of life and behavior and emotion from functional auditory and pragmatic language abilities in 9-year-old deaf and hard-of-hearing children. *Journal of Clinical Medicine*, *10*(22). https://doi.org/10.3390/jcm10225357

Ching, T. Y. C., Dillon, H., Leigh, G., & Cupples, L. (2018). Learning from the Longitudinal Outcomes of Children with Hearing Impairment (LOCHI) study: summary of 5-year findings and implications. *International Journal of Audiology*, *57*(sup2), S105–S111. https://doi.org/10.1080/14992027.2017.1385865

Crukley, J., & Scollie, S. D. (2014). The effects of digital signal processing features on children's speech recognition and loudness perception. *American Journal of Audiology*, *23*(1), 99–115. https://doi.org/10.1044/1059-0889(2013/13-0024)

Culbertson, J. L., & Gilbert, L. E. (1986). Children with unilateral sensorineural hearing loss: Cognitive, academic, and social development. *Ear and Hearing*, *7*(1), 38–42. https://doi.org/10.1097/00003446-198602000-00007

Cummings, A., Saygin, A. P., Bates, E., & Dick, F. (2009). Infants' Recognition of Meaningful Verbal and Nonverbal Sounds. *Language Learning and Development*, *5*(3), 172–190. https://doi.org/10.1080/15475440902754086

Curtin, M., Herman, R., Cruice, M., & Morgan, G. (2021). Assessing parent-child interaction in infant deafness. *Current Opinion in Otolaryngology and Head and Neck Surgery*, *29*(3), 200–203. https://doi.org/10.1097/MOO.0000000000000710

Erber, N. (1977). Evaluating Speech-Perception Ability in Hearing Impaired Children. In F. H. Bess (Ed.), *Childhood Deafness* (pp. 173–181). Grune & Stratton.

Gomes, H., Molholm, S., Christodoulou, C., Ritter, W., & Cowan, N. (2000). The development of auditory attention in children. *Frontiers in Bioscience*, *5*(1), d108. https://doi.org/10.2741/gomes

Graneheim, U. H., & Lundman, B. (2004). Qualitative content analysis in nursing research: Concepts, procedures and measures to achieve trustworthiness. *Nurse Education Today*, *24*(2), 105–112. https://doi.org/10.1016/j.nedt.2003.10.001

Guellai, B., Somogyi, E., Esseily, R., & Chopin, A. (2022). Effects of screen exposure on young children's cognitive development: A review. *Frontiers in Psychology*, *13*(August), 1–12. https://doi.org/10.3389/fpsyg.2022.923370

Iverson, J. M. (2010). Developing language in a developing body: the relationship between motor development and language development. *Journal of Child Language*, *37*(2), 229–261.

https://doi.org/10.1017/S0305000909990432.Developing

Jones, C., & Launer, S. (2010). Pediatric fittings in 2010: The Sound Foundations Cuper Project. *Sound Foundations Through Early Amplification*, 187–192. http://www.phonakpro.com/content/dam/phonak/gc_hq/b2b/en/events/2010/Proceedings/Pho_Chap_12_Jones_Final.pdf

Krentz, U. C., & Corina, D. P. (2008). Preference for language in early infancy: the human language bias is not speech specific. *Developmental Science*, *11*(1), 1–9. https://doi.org/10.1111/j.1467-7687.2007.00652.x

Lesica, N. A., Mehta, N., Manjaly, J. G., Deng, L., Wilson, B. S., & Zeng, F. G. (2021). Harnessing the power of artificial intelligence to transform hearing healthcare and research. *Nature Machine Intelligence*, *3*(10), 840–849. https://doi.org/10.1038/s42256-021-00394-z

Libertus, K., & Violi, D. A. (2016). Sit to talk: Relation between motor skills and language development in infancy. *Frontiers in Psychology*, *7*(MAR), 1–8. https://doi.org/10.3389/fpsyg.2016.00475

Mulla, I., & McCracken, W. (2014). Frequency modulation for preschoolers with hearing loss. *Seminars in Hearing*, *35*(3), 206–216. https://doi.org/10.1055/s-0034-1383505

National Deaf Children's Society. (2017). *Quality Standards for the use of personal radio aids*.

Pittman, A. (2014). Children's Performance in Complex Listening Conditions: Effects of Hearing Loss. *Journal of Speech, Language, and Hearing Research*, *54*(August), 1224–1239. https://doi.org/10.1044/1092-4388(2010/10-0225)a

Pressman, L., Pipp-Siegel, S., Yoshinaga-Itano, C., & Deas, A. (1999). Maternal sensitivity predicts language gain in preschool children who are deaf and hard of hearing. *Journal of Deaf Studies and Deaf Education*, *4*(4), 294–304. https://doi.org/10.1093/deafed/4.4.294

Shultz, S., & Vouloumanos, A. (2010). Three-month-olds prefer speech to other naturally occurring signals. *Language Learning and Development*, *6*(4), 241–257. https://doi.org/10.1080/15475440903507830

Statham, C., & Cooper, H. (2013). FM for babies and toddlers: making the most of the opportunity. *British Association of Teachers of the Deaf Magazine*.

Vohr, B., St Pierre, L., Topol, D., Jodoin-Krauzyk, J., Bloome, J., & Tucker, R. (2010). Association of maternal communicative behavior with child vocabulary at 18-24months for children with congenital hearing loss. *Early Human Development*, *86*(4), 255–260. https://doi.org/10.1016/j.earlhumdev.2010.04.002

Wang, Y., Hartman, M., Aziz, N. A. A., Arora, S., Shi, L., & Tunison, E. (2017). A Systematic Review of the Use of LENA Technology. *American Annals of the Deaf*, *162*(3), 1–14.

Werfel, K. L., Reynolds, G., & Fitton, L. (2022). Oral Language Acquisition in Preschool Children Who are Deaf and Hard-of-Hearing. *Journal of Deaf Studies and Deaf Education*, *27*(2), 166–178. https://doi.org/10.1093/deafed/enab043

Werner, L. (2007). What Do Children Hear? How Auditory Maturation Affects Speech Perception. *The ASHA Leader*, *12*(4), 6–33. https://doi.org/10.1044/leader.ftr1.12042007.6